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## A Baseline Lunar Mine

Richard E. Gertsch

In this section I propose a modest lunar mining method. It illustrates the problems to be expected in lunar mining and how they might be solved. While the method is quite feasible, it is, more importantly, a useful baseline system against which to test other, possibly better, methods. Our study group proposed the slusher to stimulate discussion of how a lunar mining operation might be successfully accomplished. Critics of the slusher system are invited to propose better methods. The group noted that while nonterrestrial mining has been a vital part of past space manufacturing proposals, no one has proposed a lunar mining system in any real detail (Carrier 1979, Williams et al. 1979). The group considered it essential that the design of actual, workable, and specific lunar mining methods begin immediately.

Based on an earlier proposal (Gertsch 1983), the method is a three-drum slusher, also known as a cable-operated drag scraper (Ingersoll-Rand Company 1939, Church 1981). Its terrestrial application is quite limited, as it is relatively inefficient and inflexible.

The method usually finds use in underwater mining from the shore and in moving small amounts of ore underground. It uses the same material-moving principles as more efficient, high-volume draglines.

The slusher is proposed here because the LOX-to-LEO project is a very small operation by terrestrial standards and requires a method that minimizes risk. The three-drum slusher has already proven itself in this context. It has the advantages of simplicity, ruggedness, and a very low mass to be delivered to the Moon. When lunar mining scales up, the lunarized slusher will be replaced by more efficient, high-volume methods, as has already happened here on Earth.

### The Machine and Duty Cycle

Before discussing the advantages of the machine in a small-scale startup lunar mining scenario, I will describe the slusher and its duty cycle. It consists of the following modules (see figs. 18 and 19):

Figure 18

### The Mobile Lunar Slusher

Several features of a mobile slusher (cable-operated drag scraper) are shown in this perspective view. The scraper loading material in the center of the pit will continue to load material until it reaches the discharge point or loading station to the left. In the method proposed in the text, the slusher will load into a mobile mill module with the aid of a conveyor. (Neither the conveyor nor the mill module is shown here. The module behind the loading station is a transporter.) The mobile power unit/loading station will be anchored (not shown) to counter the forces on it. The function of the two anchored pulleys should be clear from the illustration. The "box-type" slusher bucket has enclosed sides, which keep the very fine lunar material from spilling out while being loaded and transported.

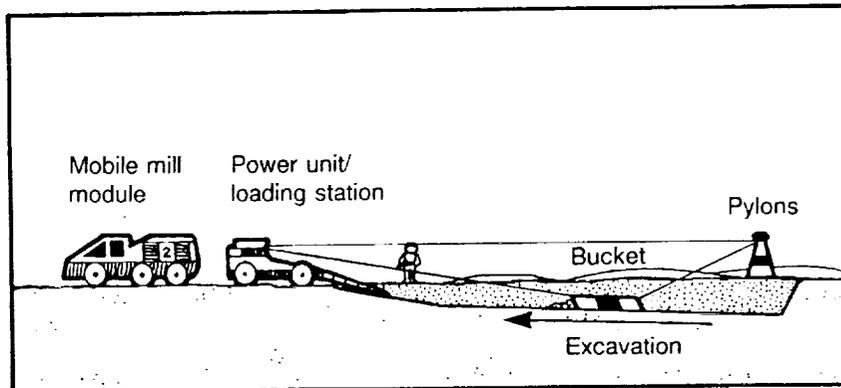
1. A mobile power unit and loading station—including three drums around which the cables are wound, a mechanism to place anchors, a mechanism to change tools, an optional operator cab, a dozer blade, and a conveyor to load material into the electrostatic separator
2. Three lengths of cable to operate the scraper or other mining tools
3. Two anchored pulleys
4. Interchangeable working tools, including scrapers, rakes, plows, and rippers



Figure 19

### Side View of the Mobile Lunar Slusher

This side drawing of the slusher shows the mobile mill module behind the combination power unit and loading station. In this setup, the material from the slusher bucket is dumped directly into the mill module. The pylons holding the pulleys must be firmly anchored. They position the bucket when it is pulled out from the loading station into the mining area.



The duty cycle starts with machine setup. The mobile power/loader unit places two pulleys at appropriate locations at the mine site. They could be anchored by large augers in the firm regolith below the loose soil or by other methods. The preferred anchoring method depends on specific site characteristics. After the pulleys are anchored, the power unit similarly anchors itself. The two pulleys and the power unit form a V-shaped mining area. Because machine setup is done only infrequently, is a complex job, and requires firm anchoring, it could

be left as a manual operation. For one reason, the anchoring augers might hit buried rocks before they are successfully emplaced. Further study may show that automated or teleoperated setup is also feasible and more desirable.

In this short paper, it is impossible to cover adequately all the alternatives and options, even within a well-defined system such as the slusher. However, I will mention one major alternative—a stationary power/loader unit (fig. 20), which is the terrestrial configuration. In this case, the

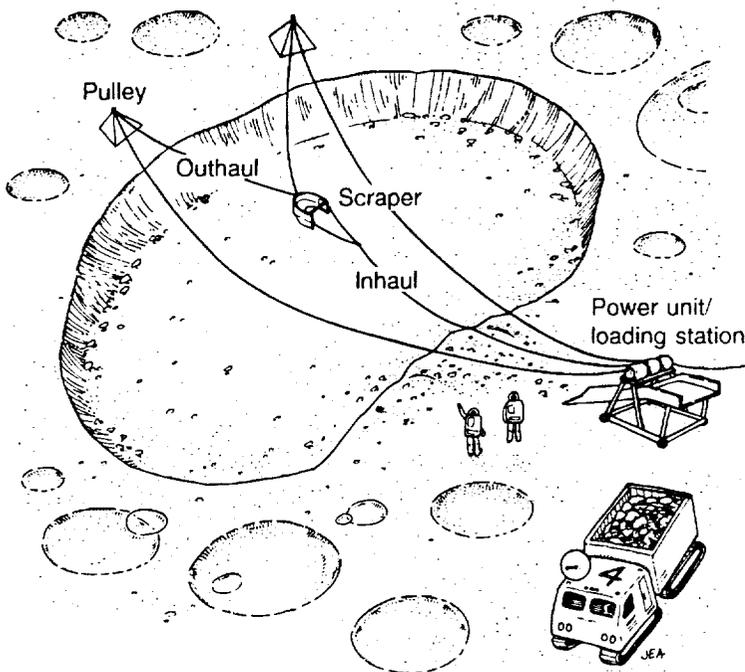


Figure 20

#### The Stationary Lunar Slusher

A stationary lunar slusher would have the same operational features as the mobile slusher. Because it is not self-propelled, it is much simpler and lighter; however, for the same reason, it requires another vehicle to move it from site to site.

From Gertsch 1983.

slusher itself would be far simpler, but such a system would require an auxiliary vehicle to transport the slusher from site to site and set it up. A stationary slusher would be less able to remove unexpected obstacles from the pit, as I will discuss. Either way, the excavation duty cycle is basically the same.

After setup, the excavation duty cycle begins with the scraper (or other tool) at the loading station. The scraper can be moved to any point within the V by a combination of tensions on the two outhaul cables. After reaching the desired position, usually as far into the pit as possible, the scraper is pulled back to the power/loader unit by the inhaul cable. During inhaul, a combination of inhaul force and scraper weight (fig. 21) causes the scraper to fill with loose regolith and carry it back to the power/loader unit. Here the material is pulled up the ramp, discharged from the scraper onto the conveyor, and loaded directly into the mill module.

The mill is the electrostatic separator described by Agosto in the section on beneficiation. The separator should be in direct contact with the slusher. This eliminates rehandling of the mined material, resulting in a significant energy saving, since 90 percent of the mined material will be rejected by the separator. The waste from the separator is dumped away from the production area by ballistic transport or another method. Waste transport need only be far enough to keep the separator and slusher from being buried in their own waste.

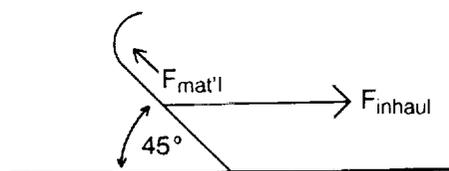
The box-like scraper will have closed sides to keep the very fine regolith from spilling out, as has been the terrestrial experience.

Because the machine defines its own mining area and machine motions are repetitive, the scraping operation is a reasonable candidate for automation. Feedback control for automatic loading of the scraper will be supplied through sensing the inhaul cable tension. Loading always requires complex motion control, but the problem is more easily resolved with a limited-motion machine such as the slusher than with fully mobile equipment, such as front-end loaders, which have unlimited freedom of motion.

Figure 21

#### Forces on a Hoe Scraper

The 45-degree scraping angle is considered optimum. The angle has been determined by many years of terrestrial experience. It seems most likely that this angle will be the same for the Moon, but can we be sure? One missing force vector is the weight of the bucket. For proper operation, the weight of the bucket may need to be augmented with lunar rocks or other material.



After mining starts, the mobile power unit generally does not move. If an obstacle is uncovered in the pit, the mobile version of the power/loader unit can detach from its anchor and move into the pit. (The anchor is not removed from the soil unless the machine is moving to another site.) To facilitate pit work, the loading ramp is tilted up and a dozer blade extends to its working position. The blade can push boulders out of the pit or mine a small selected area. Because the power/loader unit is lightweight and consequently has poor traction characteristics, it must pull against the outhaul cables when it works a load in the pit. The complexity and uniqueness of this job argue against automating it, but automation is not impossible and teleoperation is a possibility. Both setup and power unit pit work can be done by teleoperation, except for handling severe unforeseen problems that require human intervention.

During normal operation, electric power is supplied to the power/loader unit by a stationary cable. When the power/loader unit works the pit, it gets its power through a cable reel located at the anchor. One advantage of stationary mining

equipment such as the slusher (even the mobile version moves very little during excavation) is simplicity of power supply. Most mobile terrestrial equipment has diesel power, which is rugged, capable, efficient, and, most importantly, onboard. These loaders are very flexible and rugged earth-movers. The lunar alternatives are less satisfactory. Lunar loaders with onboard power would probably use electric motors driven by fuel cell or battery technology. Both are expensive options. Versions with external power must be fed electricity through a trailing cable. Terrestrial experience has shown that trailing cables are high maintenance items, but adaptation to the Moon is possible. Another possibility is a new-technology internal combustion engine, but developing the engine and finding lunar fuel sources are difficult problems.

### **The Lunar Environment and Machine Design Principles**

The major reason for proposing the three-drum slusher is to illustrate problems to be expected in a lunar mining project.

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### **Simplicity in Design and Operation**

Compared to other mining machinery, the three-drum slusher is quite simple in design and operation. This simplicity yields several interrelated advantages.

1. Fewer moving parts, resulting in fewer failures per operating hour
2. Simpler repair, reducing downtime after a failure
3. Smaller inventory of repair parts, hence less weight to transport to the Moon
4. Simpler parts, with faster adaptability to lunar manufacture
5. Less redesign for lunar conditions, with consequently lower R&D costs
6. Fewer degrees of freedom than mobile equipment, and therefore relative ease of automation
7. Fewer project startup problems

### **Traction Independence**

Mobile mining equipment depends on traction to generate sufficient loading forces on the blade or scraper. Most terrestrial mobile

equipment loads near its traction limit. On the Moon, reduced gravity creates a less favorable inertia:traction ratio. Increases in traction are achieved by increases in mass, but increases in mass add inertia, which decreases control of a moving machine. To achieve the same traction as on the Earth, a mobile machine on the Moon would have to have six times as much mass. This greater mass would cause correspondingly higher inertial resistance to turning and slowing.

Slusher loading forces are supplied through the cable, thus almost eliminating traction problems. The scraper bucket will have to be more massive than on Earth, simply to cause the bucket to fill. To lower launch weight, the extra mass needed by the scraper bucket can be supplied by lunar rocks.

Since the slusher is a relatively low-production method, upscale lunar mining projects will eventually use mobile mining methods. It is necessary to address inertia-traction problems as early as possible. Further study may find that long-term considerations argue for using mobile equipment from the very beginning. As with the scraper bucket, the extra traction mass can be supplied by lunar materials. Perhaps traction could be improved by new tread or track designs.

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### **Mining Flexibility and Selectivity**

The lunar slusher differs from the terrestrial slusher by one major design addition: the power unit is mobile rather than stationary. This allows the machine to set itself up and eliminates the need for an auxiliary vehicle. Most important, by adding a dozer blade, the machine can doze undesirable rocks from the pit. Such large rocks would impede mining operations if the power unit were stationary.

The mobile power unit makes the machine more selective. By allowing the power/loader unit to reposition, the slusher has some ability to separate different soils during the mining process or to go into the pit and mine a small area of interest.

### **Mining Tools for Selecting Particle Size and Breaking Regolith**

The ability to change from a scraper to a rake allows the machine to select different size fractions. For example, if fines are required, the area can be raked on the outhaul, so that oversized rocks

are moved to the far side of the pit. Then the rake can be exchanged for a scraper to mine the remaining fines. If larger sizes are desired, they can be raked in on the inhaul.

Other tools, such as rippers or plows, are used to break difficult ground. Lower levels of lunar regolith appear to have a high degree of compaction (Carrier 1972) and must be broken before mining can take place. Although it is the usual terrestrial practice, chemical explosive blasting appears to be prohibited by the high cost to transport the explosives to the Moon. The ripper or plow greatly increases machine working depth. It has already been established that the slusher, unlike mobile loading equipment, is independent of traction. This traction independence allows the slusher to break difficult ground while still maintaining a light weight. More lunar geotechnical engineering data is needed, however, and the design of the ripper is unknown. The ripper probably needs an attached weight to force it into the regolith. A plow may be better than a ripper, as its shape helps pull it into the soil, making it less gravity dependent.

### High-Tech Low-Tech Mix

The redesigned slusher exemplifies a design philosophy favored by the study group. The basic machine design is nearly 100 years old and has a track record proven in many applications. See figure 22. In a lunar application, the basic operating principles remain unchanged but the machine becomes lighter, stronger, and more efficient by

liberal use of advances in materials science. Light, high-strength alloys or graphite fiber might replace steel in the machine's structural and wear members. Graphite fibers might replace steel cables. Other opportunities to improve the slusher should present themselves. Thus, the lunar machine is a low-tech off-the-shelf design with high-tech execution.

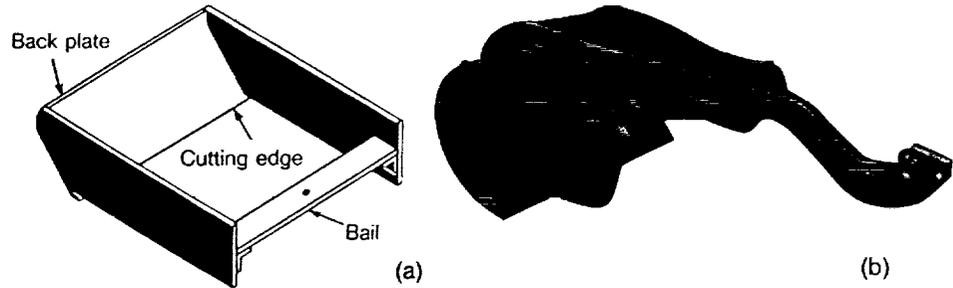


Figure 22

#### Box-Type Slusher Scrapers

##### a. Drawing of a Box-Type Scraper

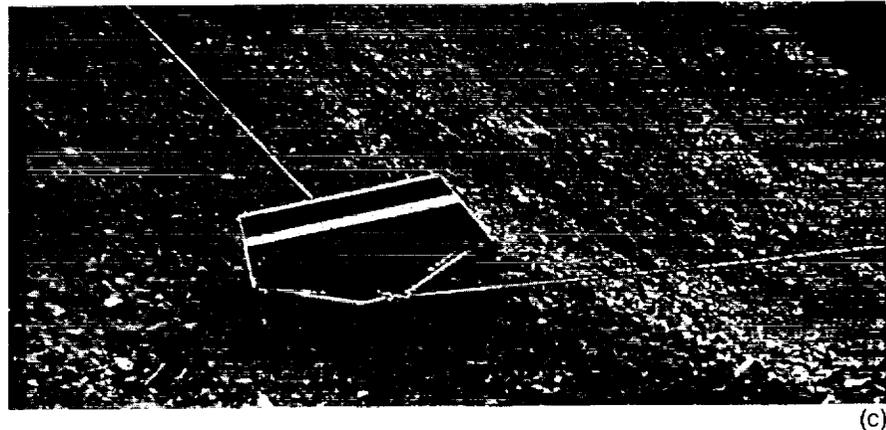
##### b. Painting of a Full-Box Type Scraper

[Shown with a long bail and medium-length side plates.]

##### c. Photograph of a Box-Type Scraper

[Manufactured in the 1930s of steel plate construction in use on a stock pile.]

All three taken from *Modern Methods for Scraper Mucking and Loading*, prepared, edited, and published by the Ingersoll-Rand Company in 1939.



## Two Environmental Factors

In addition to one-sixth gravity, there are two other significant lunar environmental factors worth noting: temperature extremes and electrostatic dust. Temperature extremes are easily answered by shutting down during the lunar night. Heating selected equipment components is feasible, if more expensive. Electrostatic dust is more of a problem. Machinery bearings must be protected, a problem exacerbated by the lunar vacuum, where lubricants may evaporate. One significant feature of the slusher is that it uses very few bearings, even in the mobile version. Lunar bearing designs and lubrication methods must be developed regardless of the mining method used.

## Machine Specifications and Fleet Mix

The specifications and fleet mix I present are for the mobile lunar slusher. The reader should note that alternative methods, such as the stationary slusher, were included to illustrate lunar mining design problems and are not specified here. The data given below are for the proposed baseline mobile lunar three-drum system.

The needed raw material for a 100-metric-ton LOX-to-LEO project is 40 000 metric tons. The machine specified below is oversized by a

factor of 2.5 or a yearly rate of 100 000 metric tons. This oversizing is to ensure the production is easily accomplished, while demonstrating that a significantly oversized machine is relatively lightweight. Even with this large oversizing, the hourly production is about 25 metric tons per hour. This rate is close to the lowest rate shown on the production table of one manufacturer (Ingersoll-Rand Form 4273A 5-G1 1971).

### Specifications:

Yearly production	100 000 metric tons
Span and reach	50 meters
Mined depth	2 meters
Scraper capability	2 cubic meters
Mobile slusher weight	4.5 metric tons
Auxiliary vehicle weight	1.5 metric tons
Ballistic transporter	1 metric ton
Spare parts and tools	2 metric tons
Operation and maintenance	2 people
Foundry (optional)	5 metric tons
Total weight (without foundry):	9 metric tons

### Fleet:

- 1 mobile slusher
- 1 auxiliary vehicle with small multipurpose crane
- 1 ballistic transporter

## Lunar Mining Operations

### Production Profile

The baseline self-propelled slusher excavates a triangular area 50 meters in base and height. At a mining depth of 2 meters, approximately 9000 metric tons are excavated per setup.

Approximately one setup per lunar day yields a yearly raw material production of 100 000 metric tons.

Mining would cease during the night, as the extremely low temperatures would make operation difficult. But milling could continue, as the mill is more easily protected from the environment. Production figures are based on terrestrial experience; lunar gravity will allow increases without increasing

machine size. It should be noted that production can readily be increased by manipulating several machine variables without significantly changing machine weight. Variables such as bucket size, span, reach, and motor power all affect production. No attempt was made to optimize these factors; instead the machine was oversized to show a very basic feasibility. Empirical optimization is required during design and prototype testing.

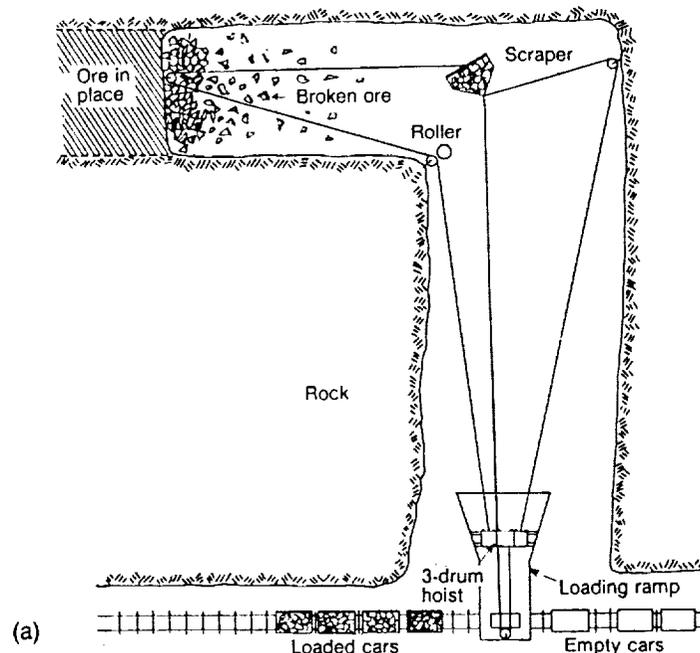
Although the normal mining pattern is a V, mobilizing the power/loader unit allows more flexible patterns (fig. 23). The mobile unit allows the machine to excavate more convenient rectangular areas rather than triangular ones.

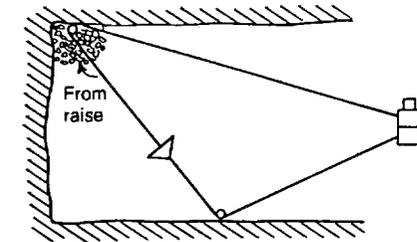
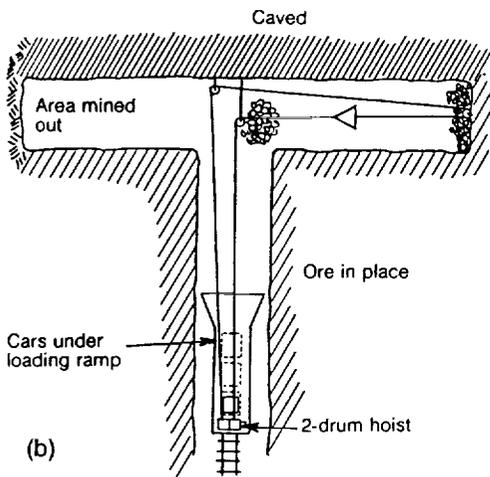
Figure 23

### Various Slusher Mining Patterns

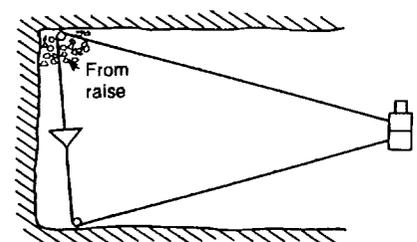
These underground slusher mining patterns demonstrate the slusher's flexibility in mining different shaped areas. Figure a shows a three-drum slusher scraping around a corner. Figure b shows a two-drum slusher scraping around a corner, but note that it takes two scraping operations. Figures c and d show how a changing setup allows a two-drum slusher to mine outside its restricted narrow path. Both the two- and three-drum slushers can mine a wide variety of areas: triangles, rectangles, right angles, etc. However, each different setup requires downtime to reset the pulleys or the power/loader unit.

Taken from *Modern Methods for Scraper Mucking and Loading* by the Ingersoll-Rand Company, 1939.





(c)



(d)

Some weight savings could be gained by using a two-drum slusher. With one outhaul cable instead of two, the machine excavates a straight line rather than a triangle. The decrease in flexibility may not be worth the small weight savings, but the two-drum solution should be investigated. By moving the power/loader unit or the pulleys, the two-drum slusher can be made to excavate a rectangular area, but the moves slow the rate.

### Modular Components

Every opportunity should be taken to divide the slusher (and other equipment) into modular components. The modules should

be as interchangeable and transportable as possible. Two general types of modules envisioned are large functional modules, such as mining units, material crushers, and electrostatic separators, and small equipment modules, such as electric motors and power distribution panels.

Modularity increases flexibility and reduces downtime without adding equipment weight.

1. A component needing repair can be replaced onsite with a working unit. The defective unit can then be repaired onsite or in the shirt-sleeve environment of a pressurized shop.

2. Quick component replacement allows production to continue when one component breaks. When many components break, a producing unit can frequently be assembled from the remaining units.
3. Catastrophic failure of a module, such as an electric motor, will not hamper production, as the whole unit can be replaced.
4. Increasing production simply means adding more components rather than redesigning or rebuilding the existing facilities. Upgrading one part of the operation with new designs or technology is facilitated by replacing the old components with the new.

Accomplishing modularity is relatively easy in small-production mining facilities. (By terrestrial standards, the lunar slusher operation is very small.)

#### **Auxiliary Vehicle**

A small, self-propelled auxiliary vehicle will probably be necessary, even with a mobile slusher or other mobile mining method. It will find use hauling broken components to the repair shop and replacement modules to their operating positions, as well as hauling people and materials back and forth. It

should have a crane to aid in constructing habitats and repairing equipment. Adding a small conveyor to the vehicle would allow it to heap up loose regolith for habitat shielding. This general-purpose vehicle will be smaller than the vehicle required to move a stationary slusher from site to site.

#### **Shop Facilities**

A pressurized repair shop would facilitate complex repairs by providing a shirt-sleeve environment. There is no good reason to rewind an electric motor in a vacuum. Since lunar dust is ubiquitous and insidious, some system for removing dust from the shop and its equipment must be provided. Equipment from the outside must be cleaned of dust before it enters the shop.

However, a shop would add significant launch weight unless it could be fabricated on the Moon. Launch weight considerations dictate a careful mix of tools, equipment, and spare parts for the shop. The shop and repair activities are there to keep the mine operating while helping to keep transportation costs for tools and spare parts to a minimum.

In addition to tools and spare parts, the shop could eventually have a small adjacent foundry to cast pulleys, bearings, and other

easily fabricated parts. The foundry will probably not be in the shop but outside in the vacuum. This plan assumes lunar metal production.

Fiberglass ropes of lunar origin to replace Earth-made cables are also candidates for early lunar manufacture, as glass is a byproduct of LOX production. Glass manufacturing methods were not considered here.

#### **Mine Waste Disposal**

Depending on required products and milling processes, some fraction of the mined material will be waste which must be removed from the production area. This fraction can be quite significant (e.g., terrestrial copper operations yield only 10 kg of product per metric ton of ore; thus, 1990 kg of that tonne is waste). The LOX-to-LEO project will generate two types of waste. Fines waste is the soil fraction rejected by electrostatic separation. Slag waste results from the smelting process. Production of liquid

oxygen from regolith that is 10 percent ilmenite will generate mostly fines waste, on the order of 90 percent of the material mined or 36 000 metric tons per year. Providing a vehicle for waste disposal would add significant launch weight, and the waste disposal options must be studied.

Robert Waldron and David Carrier\* have both proposed a ballistic transport mechanism that could be usable in lunar mining. It is well suited to removing fines waste. Using a simple mechanism such as an Archimedean screw (see box) or conveyor flights, it is possible to ballistically transport fines waste several hundred meters away from the production area. Their preliminary calculations indicate that the mechanism could be built at a reasonable weight. A ballistic transporter, along with a storage and feed bin, could be added as part of the mill module or as a separate module. The ballistic transporter could also be used to heap up material for habitat shielding.

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\*Personal communications.

The following is one of a series of 5-minute radio programs. Entitled *The Engines of Our Ingenuity*, the series is written by mechanical engineer John H. Lienhard and presented by the University of Houston's College of Engineering.

### Ceredi's Pump

Now and then I run into a student who says, "I like engineering just fine; but why should I hafta take philosophy?" He fails to see that what we do is shaped by the way we think about things—that our technology and our philosophy bend to fit each other. Here's an example:

Archimedes invented a really clever pump in the third century B.C. It's been used all over the world, ever since. It looks like a tube coiled around a long axle. You tilt the axle and put its lower end in water. Then you turn it. The open end of the tube picks up water and, as the coil turns, water passes from one loop to the next until it comes out at the upper end.

It's a pretty subtle gadget—not the sort of thing you just stumble across. Archimedean pumps were widespread in the classical world, and Roman authors described them. . . . Well, they tried to. We've just seen that they aren't easy to describe.

Archimedes' pump didn't do so well during the High Middle Ages when European attitudes were strongly shaped by Aristotle's philosophy. Aristotle very clearly separated motion into two kinds—motion in a straight line and rotary motion. These pumps mixed the motions. They used rotation to move water upward along an axis. They were anti-Aristotelian, and they were hard to find during the Renaissance.

(continued)



### Water Screw as Illustrated in Daniel Barbaro's *Vitruvius* (1567)

It is difficult to understand how this water screw might have worked. But this illustration from Daniel Barbaro's commentary on Vitruvius' *Ten Books on Architecture* shows that the device was known from classical times. Giuseppe Ceredi patented Archimedes' device in 1565, publishing his description of it the same year that Barbaro's book was printed.

Taken from Stillman Drake, 1976, "An Agricultural Economist of the Late Renaissance," *On Pre-Modern Technology and Science*, ed. Bert S. Hall and Delno C. West (Malibu, CA: Undena Publications), p. 70.

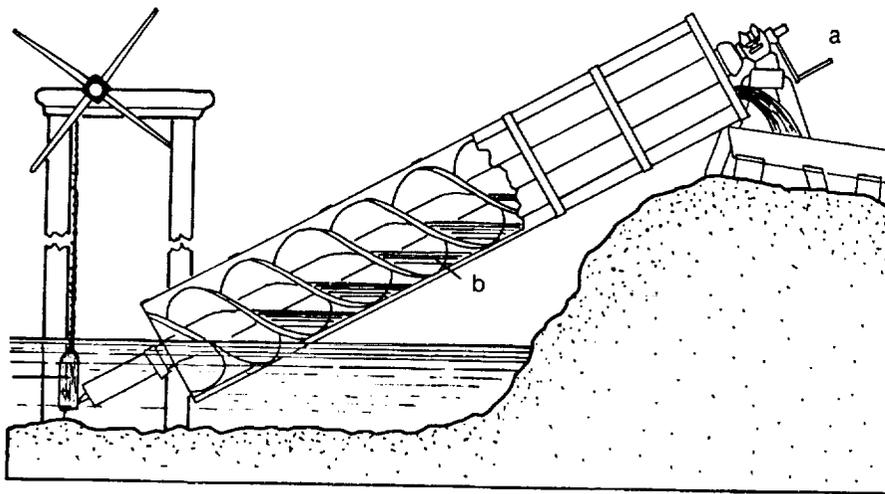
Ballistic transport of the glassy slag waste from the smelting of ilmenite will be more of a problem. For regolith that is 10 percent by weight ilmenite, the slag waste produced will be on the order of 80 percent of the ilmenite or 3200 metric tons per year. Slag waste will contain much larger and more angular particles, which are less suited to ballistic transport. If the iron is extracted, the slag waste drops to 40 percent or 1600 metric tons per year. These figures are based on 100-percent separation efficiencies.

### Costs and Time Line

Terrestrial three-drum slushers are relatively inexpensive yet rugged. A terrestrial slusher with the

production profile outlined above costs on the order of \$100 000. While the lunarized version proposed here adds several features to the terrestrial model, the redesign, addition of control circuits, and testing could be accomplished for less than \$10 million. The same design simplicity that lowers the cost of operation will help keep down the research and development cost of the slusher.

After a mining site has been selected and a lunar base has been built, placing the slusher in operation is simple and can be accomplished in about 6 months. Setup time would include final operational testing on the Moon.



#### How an Archimedean Screw Works

This modern schematic drawing shows how an Archimedean screw works. As the handle (a) is turned, a certain amount of water (b) is brought into the helical screw, which then brings the water up to a reservoir or trough.

Design, manufacture, and testing of a fully operational machine is a modest, well-defined task.

### Conclusions

Any startup project in a new environment will have many unknowns. We do not even know all the questions, much less the answers. Mining ventures are very risky here on Earth and most of them fail. The space environment with its many unknowns adds greatly to the degree of difficulty. Keeping the project small, well defined, and simple will help ensure success.

Humans' experience working in space is very limited; our experience in nonterrestrial mining does not exist. Consequently, one significant but indirect benefit of the LOX-to-LEO project will be the experience gained in exploiting lunar materials. This experience will be the basis for later, more ambitious projects, either on the Moon or on other bodies.

Whatever lunar mining method is used, the slusher or something else, must be kept as simple as possible because simplicity means lower costs. The slusher is not particularly efficient or flexible, but it is simple and cheap.

#### Ceredi's Pump (concluded)

Now, in 1565, a Renaissance agricultural engineer named Giuseppe Ceredi patented an Archimedes pump. He systematically described the installation and use of batteries of these pumps for both irrigation and drainage. But we wonder how he could be given a patent for a known device.

When you compare Ceredi's dimensioned drawings, flow calculations, and economic analysis, with the almost unreadable Roman descriptions, you begin to see why. Ceredi might well have found the idea in the old literature; but he put flesh and blood on it. After Ceredi's work, these pumps were quickly accepted across Southern Europe. They were not, as one author puts it, "something that would be created spontaneously by peasants." And they certainly weren't something that people would take up naturally in a world that didn't want to mix straight-line and rotary motion.

Ceredi had a right-brain ability to visualize. He had a left-brain ability to execute and organize detail. But he was also able to break the straitjacket of Aristotelian thinking. A few years later, Galileo took up full-scale combat with Aristotelian ideas of motion. And Ceredi's reinvention of Archimedes' pump was a harbinger of that philosophical revolution.

The LOX-to-LEO project is very small compared to terrestrial operations, even small gravel pits. The small size allows consideration of nontraditional methods such as the slusher. The simplicity of the slusher has great advantages in a small operation. If a larger lunar operation is desired, consideration of other methods is mandatory. For example, machines such as the continuous miner should be particularly suitable to mining regolith. The continuous miner has wide application and has been proven in terrestrial coal mines. Traditional methods such as the truck-loader combination can also come into play. This mining combination has long been the workhorse for a wide variety of terrestrial mines.

More complex lunar mining methods may have a greater terrestrial transfer potential. A fully automated machine may find a significant terrestrial market. If so, such methods could amortize their development costs by supplying a wider market than the Moon.

The slusher itself has unresolved problems, even for the small LOX-to-LEO project. Only a few of these problems have been mentioned here. To ensure success, any lunar mining method must solve these problems effectively. Problem definition for a lunar mine has only just begun.

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